

HYDRAULIC CALCULATION OF DIVERSION TUNNEL

[UPPER TRISHULI-1 HEP (216MW)]

2022. 10. 13

FOR APPROVAL

0	2022.10.13	DONG Z.Z.	K.J.KIM	Y.S.SON	As RN 0296
0E	2022.09.07	DONG Z.Z.	K.J.KIM	Y.S.SON	A
0D	2022.04.12	DONG Z.Z.	K.J.KIM	Y.S.SON	AN
0C	2022.01.16	DONG Z.Z.	K.J.KIM	Y.S.SON	AN
0B	2021.12.30	DONG Z.Z.	K.J.KIM	Y.S.SON	RR
0A	2021.07.12	DONG Z.Z.	K.J.KIM	Y.S.SON	First issue
REV	DATE	PREPARED	CHECKED	APPROVED	STATUS

Project

Upper Trishuli-1 HEP (216MW)

Owner



Owner's Engineer



Contractor

DOOSAN Doosan Heavy Industries & Construction

Document Title

Hydraulic Calculation of Diversion Tunnel

Discipline
Civil & Architecture

Purpose
For Construction

Revision No.

0

Document No.

UT1-C-010-CVL-DC-42001

Number of Pages

23

Hydraulic Calculation of Diversion Tunnel**RECORD OF REVISION**

<u>Rev.</u>	<u>Date</u>	<u>Page Affected</u>	<u>Description of Revision</u>
0A	12-JUL-2021		First issue
0B	30-DEC-2021		Second issue
0C	16-JAN-2022		As RN 0041
0D	06-APR-2022		As RN 0058
0E	06-SEP-2022		As RN 0126
0	13-OCT-2022		As RN 0296

Hydraulic Calculation of Diversion Tunnel

Contents

1 Analysis purpose	1
2 Reference Documents.....	1
3 Design criteria	2
4 Common Formulas and data for Hydraulic Calculation	2
4.1 Discharge capacity of Diversion Tunnels	2
4.2 Water level and discharge relationship at outlet.....	6
4.3 Monthly average discharge	7
5 Discharge capacity	7
5.1 Design flood condition in dry season.....	8
5.2 Forecast flood condition.....	8
5.3 Combined discharge condition	9
5.4 Conclusion of discharge capacity of D/T	10
6 Flow profiles in the tunnel	12
6.1 Calculating theory	12
6.2 Water surface profile calculating	14
6.3 Hydraulic jumping	17
7 Characteristic water levels	20
7.1 Diversion during dry season	20
7.2 Diversion during flood season	20
8 Conclusions	23

Hydraulic Calculation of Diversion Tunnel

1 Analysis purpose

As detail design of diversion works, the 20-year dry season design flood is considered. According to the hydrological analysis illustrated in design optimization proposal (DOP) for diversion tunnel works, the corresponding design flood discharge is 208m³/s. Overflowing of the cofferdam is considered during flood season. In addition, assuring the safety of headwork construction, the flood season flow 1367.3 m³/s of the 5-year return period flood has been employed.

The purpose of this calculation is to analyse discharge capacity of diversion tunnel in dry season, and to analyse combined discharge capacity of diversion tunnel and cofferdam in flood season.

2 Reference Documents

- (1) USACE EM 1110-2-1601 Hydraulic Design of Flood Control Channels.
- (2) USACE EM1110-2-1602 Hydraulic Design of Reservoir Outlet Work.
- (3) USACE EM 1110-2-2901 Tunnels and Shafts in Rock.
- (4) USACE EM 1110-2-2902 Conduits, Culverts, and Pipes.
- (5) Chow, V.T. 1959. Open-channel Hydraulics, McGraw-Hill, New York.
- (6) USACE, Hydraulic Design Criteria.
- (7) Open Channel Hydraulics, A. Osman Akan, First edition 2006.
- (8) Design Optimization Proposal for Diversion Tunnel Works (Rev.D), 29th Nov. 2021.
- (9) Annex 1: Arrangement drawing of diversion Tunnel.
- (10) Annex 2: Excavation and support drawing of inlet and outlet of diversion tunnel.
- (11) Annex 3: Outline drawing of inlet structure of diversion tunnel.
- (12) Annex 4: Outline drawing of diversion tunnel lining.
- (13) Annex 5: Embankment drawing of U/S cofferdam.

Hydraulic Calculation of Diversion Tunnel

3 Design criteria

During the dry season, the cofferdam is used to retain water and the diversion tunnel is used for releasing the river flow. During the flood season, the river water will flow through the cofferdam surface and the diversion tunnel.

Dry season (November to April): 1:20 AEP (Annual Exceedance Probability) flood, discharge is corresponding to 208m³/s. The dry season has been selected as 6 months' period, Diversion works are planned and designed to protect the construction objects for half year of dry season. When the flow discharge of the riverbed is lower than 208m³/s, the river water is discharged through the diversion tunnel, and under the protection of the cofferdam, constructions of the weir foundation pits will be carry out in under dry condition. The protective criteria of flood season is whole year 5-year return period flood and corresponding to the flow discharge of 1367.3 m³/s. Construction of the weir foundation pits will be suspended at this time.

- Permissible flow velocities of concrete lining in tunnel: 20m/s ~ 25m/s.
- Freeboard of cofferdam: 1.0m~1.5m
- Overtopping of cofferdam will be allowed under 1:5 AEP flood conditions.
- Permissible flow velocities of steel cages or gabion: 7m/s~9m/s.

4 Common Formulas and data for Hydraulic Calculation

The diversion tunnel is located on right bank of the river, 1:20AEP dry season flood diversion criteria shall be used, and the corresponding flow is 208 m³/s. The protection criteria is 1:5AEP in flood season corresponding flow is 1367.3 m³/s. And the reversed D shape section with cross section 5.0m×5.0m has been considered as diversion tunnel. The length of diversion tunnel is 413.042 m. The inlet invert elevation is EL.1244.5 m. The outlet invert elevation is EL.1231.0m. The detail profiles refer to the Annex 1~ Annex 5.

4.1 Discharge capacity of Diversion Tunnels

If the downstream water level is higher than the outlet tunnel crest elevation, water flow is of

Hydraulic Calculation of Diversion Tunnel

pressurized flow; otherwise, H/D is used to determine the flow regime.

If $H/D < 1.2$, free flow;

$1.5 > H/D > 1.2$, transition flow;

$H/D > 1.5$, pressurized flow;

Where:

H—upstream water head from tunnel inlet invert, m;

D—tunnel height, m.

4.1.1 Free flow hydraulic calculation

Discharge capacity is calculated as per free flow from formula:

$$Q = m\sigma_m b \sqrt{2gH_0^{1.5}} \quad (4-1)$$

Where:

b—clear width of tunnel or weir width, m;

σ_m —submergence coefficient;

m— discharge coefficient, generally take 0.34;

H_0 —the elevation difference between the upstream water surface and tunnel inlet invert, m;

g – Acceleration of gravity, $g=9.81\text{m/s}^2$.

4.1.2 Pressurized flow hydraulic calculation

(1) Calculation Formula

Calculation formula of pressurized flow:

$$Q = CA\sqrt{2gH} \quad (4-2)$$

Where,

Q— discharge, m^3/s ;

C — discharge coefficient;

A — tunnel outlet cross-section area, m^2 ;

Hydraulic Calculation of Diversion Tunnel

H — water head, H =upstream water level- downstream water level, m;

g — gravitational acceleration, $g=9.81 \text{ m/s}^2$.

(2) Calculate discharge coefficient C from formula:

$$C = \frac{1}{\sqrt{1 + \sum \xi_i \left(\frac{A}{A_i}\right)^2 + \sum \frac{2gl_i}{C_i^2 R_i} \left(\frac{A}{A_i}\right)^2}} \quad (4-3)$$

Where,

A — tunnel outlet cross-section area;

ξ_i —additional head loss coefficient, tunnel section i , A_i is cross-section area;

l_i —length of tunnel section i , corresponding cross-section area, hydraulic radius and

Chezy coefficient are A_i , R_i and C_i .

Calculate Chezy coefficient C_i from formula:

$$C_i = \frac{1}{n_i} R_i^{1/6} \quad (4-4)$$

$$R_i = \frac{A_i}{\chi_i} \quad (4-5)$$

Where,

R_i —Tunnel section hydraulic radius, m;

n_i —Tunnel roughness, for concrete liner;

χ_i —Tunnel wetted perimeter

For concrete liner, roughness n is 0.014.

(3) Calculation of head loss

Hydraulic Calculation of Diversion Tunnel

- Friction head loss

Friction head loss coefficient is calculated from formula:

$$\xi = \frac{2g}{c^2} \frac{L}{R} \quad (4-6)$$

Definitions refer to formula.

$$\sum \frac{2gl_i}{C_i^2 R_i} \left(\frac{A}{A_i}\right)^2 \quad (4-7)$$

Calculation of friction head loss is shown in table 4.1, and calculation of additional head losses from inlet to outlet is shown in table 4.2.

Table 4.1 Calculation of Friction Head Loss

n	A	A _i	χ	R	C	L	$\sum \frac{2gl_i}{C_i^2 R_i} \left(\frac{A}{A_i}\right)^2$
0.014	22.84	22.84	18.12	1.26	74.237	413.04	1.17

Table 4.2 Calculation of Total Additional Loss

Additional Losses	ξ	$\frac{A}{A_i}$	$\xi_i \left(\frac{A}{A_i}\right)^2$
Inlet loss coefficient	0.2	0.87	0.151
Inlet gate slot loss coefficient	0.1	0.91	0.083
Bend 1# loss coefficient	0.107	1	0.107
Bend 2# loss coefficient	0.082	1	0.082
Total additional losses $\sum \xi_i \left(\frac{A}{A_i}\right)^2$	/	/	0.424

Note:

Loss coefficient of bend is calculated from formula:

Hydraulic Calculation of Diversion Tunnel

$$\xi = \left[0.131 + 0.1632 \left(\frac{d}{r} \right)^{3.5} \right] \frac{\theta^{1/2}}{90^0} \quad (4-8)$$

Where,

d— tunnel width, 5.0m;

r— turning radius, bend r=50m/45m;

θ— turning angle, bend θ=60°/35°;

4.2 Water level and discharge relationship at outlet

The water level and discharge relationship at outlet is listed in Table 4.3. (data from 44 years, 1967 to 2010 at Betrawati(447) station)

Table 4.3 Water Level and Discharge Relationship at Outlet

Outlet water level(m)	Discharge(m ³ /s)
1231.53	0.00
1232.00	3.74
1232.50	23.3
1233.00	57.9
1233.50	108
1234.00	176
1234.50	263
1235.00	367
1235.50	483
1236.00	622
1236.50	758
1237.00	920
1237.50	1100
1238.00	1280
1238.50	1480
1239.00	1730
1239.50	1920
1240.00	2160
1240.50	2430

Hydraulic Calculation of Diversion Tunnel

4.3 Monthly average discharge

The monthly average discharge is listed in Table 4.4. (data from 44 years, 1967 to 2010 at Betrawati(447) station)

Table 4.4 Monthly average discharge

Month	Discharge(m ³ /s)
Jan.	43.5
Feb.	38.5
Mar.	38.4
Apr.	48.1
May	87.2
Jun.	227
Jul.	479
Aug.	546
Sep.	363
Oct.	159
Nov.	79.7
Dec.	54.7
Average	182

5 Discharge capacity

According to the detail design scheme of diversion works, the U/S cofferdam have three kinds of operation modes.

Type 1: the design flood condition is 208 m³/s (20-year return period) in dry season.

Type 2: the forecast flood condition is not more than 258 m³/s in dry season, the corresponding water level of U/S cofferdam is at 1252.50m. The water level in front of the U/S cofferdam has reached the warning level in dry season. When the estimated flow discharge of the riverbed is greater than 258 m³/s, combined with hydrological forecasts, personnel and equipment in the riverbed weir foundation pit should be evacuated out.

Type 3: the combined discharge condition. The protection criteria whole year 5-year return period) withstand flood of diversion works is 1367.3 m³/s. The river water is discharged

Hydraulic Calculation of Diversion Tunnel

through the diversion tunnel on the right bank and the overflowing cofferdam. The crest elevation of hard-fill cofferdam is at EL.1253.00 m.

5.1 Design flood condition in dry season

According to the detail design scheme of diversion works, the design flood criteria in the dry season is 20-year return period flood corresponding to the discharge of 208 m³/s occurs.

After pressurized flow hydraulic calculation, discharge coefficient C, equals to 0.6136, the diversion tunnel discharge capacity refer to Table 5.1.

Table 5.1 Type 1 Discharge Capacity of Diversion Tunnel

Discharge (m ³ /s)	Inlet water level(m)	Flow regime	Flow velocity of outlet (m/s)
20.00	1246.42	free flow	2.83
40.00	1247.55	free flow	4.59
60.00	1248.49	free flow	5.94
80.00	1249.33	free flow	7.21
100.00	1250.11	free flow	8.26
<u>110.61</u>	<u>1250.50</u>	<u>transition point</u>	<u>8.78</u>
120.00	1250.60	transition flow	9.27
140.00	1250.71	transition flow	10.24
160.00	1250.88	transition flow	11.10
180.00	1251.08	transition flow	11.91
200.00	1251.30	transition flow	12.75
208.00	1251.39	transition flow	13.08

5.2 Forecast flood condition

According to the detail design scheme of diversion works, the forecast warning flood is 258 m³/s in dry season. After pressurized flow hydraulic calculation, discharge coefficient C equals to 0.6136, the diversion tunnel discharge capacity refer to Table 5.2.

Hydraulic Calculation of Diversion Tunnel

Table 5.2 Type 2 Discharge Capacity of Diversion Tunnel

Discharge (m ³ /s)	Inlet water level(m)	Flow regime	Flow velocity of outlet (m/s)
20.00	1246.42	free flow	2.83
40.00	1247.55	free flow	4.59
60.00	1248.49	free flow	5.94
80.00	1249.33	free flow	7.21
100.00	1250.11	free flow	8.26
<u>110.61</u>	<u>1250.50</u>	<u>transition point</u>	<u>8.78</u>
120.00	1250.60	transition flow	9.27
140.00	1250.71	transition flow	10.24
160.00	1250.88	transition flow	11.10
180.00	1251.08	transition flow	11.91
200.00	1251.30	transition flow	12.75
220.00	1251.54	transition flow	13.53
240.00	1251.80	transition flow	14.25
<u>253.98</u>	<u>1252.00</u>	<u>transition point</u>	<u>14.73</u>
258.00	1252.54	pressurized flow	14.87

5.3 Combined discharge condition

According to the detail design scheme of diversion works, in the flood season, the river water is discharged through the diversion tunnel and overflowing cofferdam. After pressurized flow hydraulic calculation, discharge coefficient C equals to 0.6136, the diversion tunnel discharge capacity refer to Table 5.3.

Table 5.3 Type 3 Discharge Capacity of Diversion Tunnel

Discharge of diversion tunnel m ³ /s	Inlet water level Of D/T(m)	Flow regime	Discharge of U/S cofferdam m ³ /s	Total Discharge m ³ /s
262.48	1253.14	pressurized flow	2.52	265
267.12	1253.78	pressurized flow	32.88	300
271.44	1254.38	pressurized flow	78.56	350
274.92	1254.88	pressurized flow	125.08	400
277.94	1255.31	pressurized flow	172.06	450
280.66	1255.71	pressurized flow	219.34	500

Hydraulic Calculation of Diversion Tunnel

Discharge of diversion tunnel m ³ /s	Inlet water level Of D/T(m)	Flow regime	Discharge of U/S cofferdam m ³ /s	Total Discharge m ³ /s
283.16	1256.07	pressurized flow	266.84	550
285.49	1256.42	pressurized flow	314.51	600
282.16	1256.78	pressurized flow	367.84	650
283.06	1257.09	pressurized flow	416.94	700
283.87	1257.40	pressurized flow	466.13	750
284.75	1257.69	pressurized flow	515.25	800
285.60	1257.97	pressurized flow	564.40	850
286.38	1258.24	pressurized flow	613.62	900
287.16	1258.50	pressurized flow	662.84	950
287.93	1258.75	pressurized flow	712.07	1000
288.66	1259.00	pressurized flow	761.34	1050
289.34	1259.24	pressurized flow	810.66	1100
289.98	1259.48	pressurized flow	860.02	1150
290.59	1259.71	pressurized flow	909.41	1200
291.16	1259.93	pressurized flow	958.84	1250
291.74	1260.15	pressurized flow	1008.26	1300
292.34	1260.37	pressurized flow	1057.66	1350
<u>292.54</u>	<u>1260.44</u>	<u>pressurized flow</u>	<u>1074.76</u>	<u>1367.30</u>
292.91	1260.58	pressurized flow	1107.09	1400
293.45	1260.79	pressurized flow	1156.55	1450
294.04	1260.99	pressurized flow	1205.96	1500
294.69	1261.19	pressurized flow	1255.31	1550
295.33	1261.39	pressurized flow	1304.67	1600
295.94	1261.58	pressurized flow	1354.06	1650
296.53	1261.78	pressurized flow	1403.47	1700
297.03	1261.96	pressurized flow	1452.97	1750
297.38	1262.15	pressurized flow	1502.62	1800
<u>297.57</u>	<u>1262.25</u>	<u>pressurized flow</u>	<u>1529.63</u>	<u>1827.20</u>
297.72	1262.33	pressurized flow	1552.28	1850

5.4 Conclusion of discharge capacity of D/T

According to the above different operating conditions, the discharge capacity is calculated carefully. From what has been discussed above, whether it is dry season or flood season, the

Hydraulic Calculation of Diversion Tunnel

diversion tunnel discharge capacity refers to Table 5.4.

Table 5.4 Discharge Capacity of Diversion Tunnel

Discharge of diversion tunnel m ³ /s	Inlet water level Of D/T(m)	Flow regime
20.00	1246.42	free flow
40.00	1247.55	free flow
60.00	1248.49	free flow
80.00	1249.33	free flow
100.04	1250.11	free flow
<u>110.61</u>	<u>1250.50</u>	<u>transition point</u>
120.02	1250.56	transition flow
140.00	1250.71	transition flow
160.03	1250.88	transition flow
180.03	1251.08	transition flow
200.04	1251.30	transition flow
<u>208.00</u>	<u>1251.39(1:20AEP in dry season)</u>	<u>transition flow</u>
220.04	1251.54	transition flow
240.04	1251.80	transition flow
<u>253.98</u>	<u>1252.00</u>	<u>transition point</u>
258.00	1252.54	pressurized flow
262.48	1253.14	pressurized flow
267.12	1253.78	pressurized flow
271.44	1254.38	pressurized flow
274.92	1254.88	pressurized flow
277.94	1255.31	pressurized flow
280.66	1255.71	pressurized flow
283.16	1256.07	pressurized flow
285.49	1256.42	pressurized flow
282.16	1256.78	pressurized flow
283.06	1257.09	pressurized flow
283.87	1257.40	pressurized flow
284.75	1257.69	pressurized flow
285.60	1257.97	pressurized flow
286.38	1258.24	pressurized flow
287.16	1258.50	pressurized flow
287.93	1258.75	pressurized flow
288.66	1259.00	pressurized flow

Hydraulic Calculation of Diversion Tunnel

Discharge of diversion tunnel m ³ /s	Inlet water level Of D/T(m)	Flow regime
289.34	1259.24	pressurized flow
289.98	1259.48	pressurized flow
290.59	1259.71	pressurized flow
291.16	1259.93	pressurized flow
291.74	1260.15	pressurized flow
292.34	1260.37	pressurized flow
<u>292.54</u>	<u>1260.44(1:5AEP)</u>	<u>pressurized flow</u>
292.91	1260.58	pressurized flow
293.45	1260.79	pressurized flow
294.04	1260.99	pressurized flow
294.69	1261.19	pressurized flow
295.33	1261.39	pressurized flow
295.94	1261.58	pressurized flow
296.53	1261.78	pressurized flow
297.03	1261.96	pressurized flow
297.38	1262.15	pressurized flow
<u>297.57</u>	<u>1262.25(1:20AEP)</u>	<u>pressurized flow</u>
297.72	1262.33	pressurized flow

6 Flow profiles in the tunnel

6.1 Calculating theory

For the gradually-varied flow profiles, one form of the gradually-varied flow equation as:

$$\frac{dE_s}{ds} = i - J$$

i —energy slope, represents the slope of the energy grade line.

J —friction slope.

s —the displacement in the flow direction.

E_s —the specific energy, is defined as the energy head relative to the channel bottom.

For rectangular channels, it is convenient to work with the unit width of the channel. Defining

Hydraulic Calculation of Diversion Tunnel

$q=Q/b$ =discharge per unit width, the specific energy can be written as

$$E = h + \frac{\alpha q^2}{2gh^2}$$

Where

α —energy correction coefficient, for regular channels often set equal to 1.0 for simplicity.

For critical flow in rectangular channels, a simple relationship between the critical depth h_k , and critical flow specific energy, E_k , as

$$h_k = \sqrt[3]{\frac{\alpha q^2}{g}}$$

In practice, we apply a finite difference approach to calculate the gradually-varied flow profiles. In this approach, the channel is divided into short reaches and computations are carried out from one end of the reach to the other.

In the standard step method, the flow depths are calculated at specified locations. As in the direct step method, we know the flow depth and velocity at one end of a channel reach.

Assuming depth of section p is h_p , and the spacing Δs_p between two sections is known. We can determine the h_{p+1} of section $p+1$, by equation iteratively.

$$h_p + \frac{\alpha Q^2}{2gA_p^2} \pm \Delta s_p \left(i - \frac{Q^2 n^2}{2A_p^2 R_p^{4/3}} \right) = h_{p+1} + \frac{\alpha Q^2}{2gA_{p+1}^2} \pm \Delta s_p \left(i - \frac{Q^2 n^2}{2A_{p+1}^2 R_{p+1}^{4/3}} \right)$$

Where, the $p=1,2,3, \dots$

Q — discharge, m^3/s ;

A — tunnel outlet cross-section area, m^2 ;

h — water depth, m ;

g — gravitational acceleration, $g=9.81 \text{ m/s}^2$;

R — Tunnel section hydraulic radius, m ;

Hydraulic Calculation of Diversion Tunnel

n — Tunnel roughness.

6.2 Water surface profile calculating

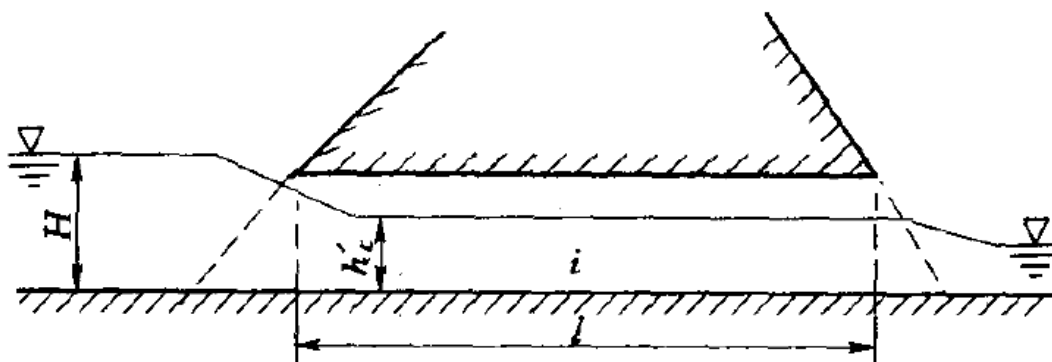
According to the discharge capacity of D/T, the calculation of water surface profiles is applied to the critical discharge flow $110.61 \text{ m}^3/\text{s}$ (free flow), $208 \text{ m}^3/\text{s}$ (AEP 1:20 dry season), $278.05 \text{ m}^3/\text{s}$ (pressurized point).

(1) Critical discharge flow $110.61 \text{ m}^3/\text{s}$

For the free flow, the discharge flow calculation is in line with open channel. According to energy equation, the basic parameters of discharge flow $110.61 \text{ m}^3/\text{s}$ are as follows.

Table 6.1 Basic parameters of discharge flow $110.61 \text{ m}^3/\text{s}$ condition

D/T height (m)	Inlet invert elevation (m)	Head water Elevation (m)	D/T invert slop (%) i	Discharge of D/T (m^3/s)	Critical slop(%) i_k	D/S water level m
5.0	1244.50	1250.50	3.32	110.61	0.4	1233.52



Because of the D/T invert slop $i > i_k$, the discharge capacity is not affected by length.

So the critical water depth of supercritical flow can be determined.

Hydraulic Calculation of Diversion Tunnel

Table 6.2 Result of discharge flow 110.61 m³/s condition

Item	Critical water depth (m)	Outlet water depth (m)	Outlet total water head (m)
Result export	3.75	1.8	10.22

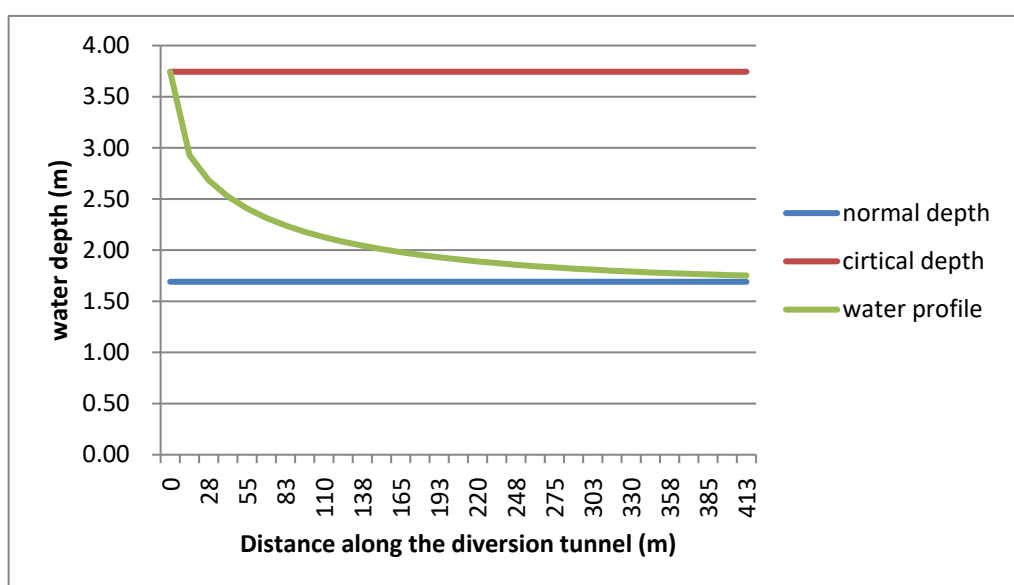
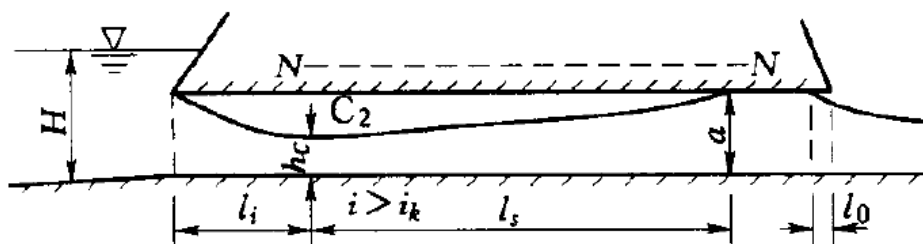


Figure 6.1 Water profile of discharge flow 110.61 m³/s

(2) Critical discharge flow 208 m³/s



For the transition flow, the basic parameters are as follows.

Hydraulic Calculation of Diversion Tunnel

Table 6.3 Basic parameters of discharge flow 208 m³/s condition

D/T height (m)	Inlet invert elevation (m)	Head water elevation(m)	D/T invert slop (%) i	Discharge of D/T (m ³ /s)	Critical slop(%) i_k	D/S water level m
5.0	1244.50	1251.30	3.32	208	0.49	1234.18

Because of the D/T invert slop $i > i_k$, the discharge capacity is not affected by length.

So the critical water depth of supercritical flow can be determined.

Table 6.4 Result of discharge flow 208 m³/s condition

Item	Critical water depth h_c (m)	l_i (m)	l_o (m)	l_s (m)	Critical length l_{ks} (m)	Outlet area (m ²)	Outlet velocity (m/s)
Result export	2.9	7	2.5	303	312.5	22.8	8.8

Because of the critical length $l_{ks} < \text{Length of D/T}$, this flow regime should be avoided.

According to the monthly average discharge, in the dry season the mean monthly flows are all less than 110.61 m³/s, and all are free flow.

The discharge flow of 110.61~294.54 m³/s condition is rather transient, so there is little influence on the operation of tunnel safely. The outlet total water head (E_0) is 9.1m.

(3) Critical discharge flow 292.54 m³/s

For the pressurized flow, the basic parameters are as follows.

Hydraulic Calculation of Diversion Tunnel

Table 6.5 Basic parameters of discharge flow 292.54 m³/s condition

D/T height (m)	Inlet invert elevation (m)	Head water elevation(m)	D/T invert slop (%) i	Discharge of D/T (m ³ /s)	Critical slop(%) i_k	D/S water level m
5.0	1244.50	1260.5	3.32	292.54	0.56	1238.20

Table 6.6 Result of discharge flow 292.54 m³/s condition

Item	Outlet invert elevation (m)	Additional head loss coefficient	Friction head loss coefficient	Outlet section area (m ²)	Outlet velocity (m/s)
Result export	1231	0.49	1.17	22.8	14.0

Considering the head loss, the outlet total water head (E_0) is 22.4m.

6.3 Hydraulic jumping

The D/S slab outside of D/T tunnel is concrete material, the cross section width of the concrete slab is 9m~16m, and the open channel is gradually varied. For ease of calculation, the calculation model is simplified to rectangular open channel.

We can determine the flow depth h' , at the super critical depth location by writing the energy equation between this section and a section just at the outlet of the tunnel. Neglecting the energy loss between the two sections, we can write the supercritical depth.

$$E_0 = h' + \frac{q^2}{2g\varphi^2 h'^2}$$

where,

Hydraulic Calculation of Diversion Tunnel

ϕ —velocity coefficient, take as 0.95.

h' —supercritical depth, m.

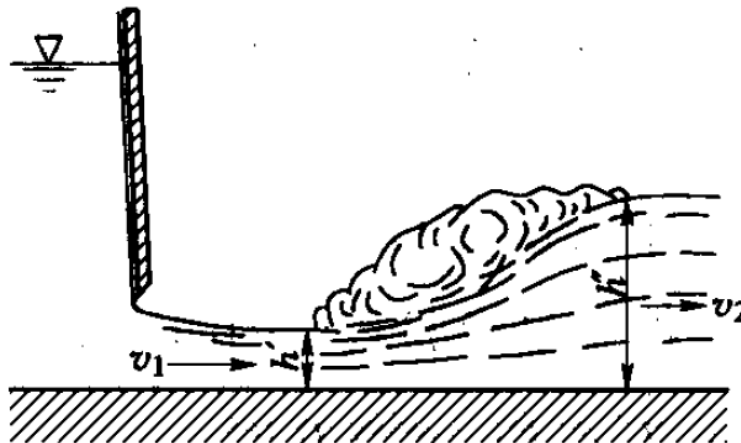
q —discharge per unit width, $\text{m}^3/\text{s}/\text{m}$.

the conjugate depth h'' , the two depth h' and h'' should satisfy the hydraulic jump equation, rewritten here as

$$h'' = \frac{h'}{2} (\sqrt{1 + 8Fr^2} - 1)$$

where Fr = Froude number, for a rectangular section with constant width, we can evaluate the Froude number as

$$Fr = q / (h' \sqrt{gh'})$$



Hydraulic Calculation of Diversion Tunnel

Table 6.7 Hydraulic jumping parameters of different discharges

Discharge (m ³ /s)	110.61	208	292.54
Single discharge or combined	Single	single	combined
Outlet E ₀ (m)	10.22	9.1	22.4
Open channel average width (m)	12.5	12.5	12.5
Supercritical depth h'(m)	1.8	2.9	1.8
Conjugate depth h''(m)	2.5	3.19	7.03
Critical depth of open channel(m)	2.0	3.05	3.82
D/S water elevation (m)	1233.52	1234.18	1238.20
D/S water depth (m)	2.52	3.18	7.2
Velocity (m/s)	3.5	5.3	3.9
Length of jumping (m)	3.6	2.0	36.1
Type of hydraulic jumping	Critical jumping	Critical jumping	Submerged jumping

From the calculation of jumping, the outlet open channel already has paved with concrete slab and gabion. So, under the design flood condition, the protection measures of tunnel outlet are feasible.

Hydraulic Calculation of Diversion Tunnel

7 Characteristic water levels**7.1 Diversion during dry season**

During dry season (November to April), the water discharges from diversion tunnel. The flow (1:20AEP dry season diversion standard) is $208\text{m}^3/\text{s}$, and the corresponding outlet water level is 1234.18m. After hydraulic calculation, the inlet water level is 1251.5m.

7.2 Diversion during flood season

During flood season (May to October), the water discharges from upstream cofferdam and tunnel. The flow (1:5AEP and 1:20AEP flood season diversion standard) is $1367.3\text{m}^3/\text{s}$ and $1827.2\text{m}^3/\text{s}$, the diversion tunnel is pressurized flow and the cofferdam is free flow. The combined discharge calculation is shown in table 7.1 and table 7.2.

Hydraulic Calculation of Diversion Tunnel

Table 7.1 Combined discharge calculation (Total flow-1367.3m³/s)

Diversion tunnel	Inlet bottom Elevation (m)	Outlet bottom Elevation (m)	Upstream water level (m)	Downstream water level of Diversion tunnel outlet (m)	Discharge coefficient	Flow (m ³ /s)
	1244.5	1231	1260.5	1238.2	0.6136	292.54

Cofferdam	Crest Elevation (m)	Upstream water level (m)	Average Width (m)	submergence coefficient	Discharge coefficient	Average flow velocity of cofferdam crest (m ³ /s)	Contracted water depth(m) of cofferdam foot downstream(EL.1245.0)	Maximum flow Velocity (m ³ /s) of cofferdam foot downstream(1245.0)	Flow (m ³ /s)
	1253.0	1260.5	26	1.0	0.34	6.62	2.17	19.05	1074.76

Hydraulic Calculation of Diversion Tunnel

Table 7.2 Combined discharge calculation (Total flow-1827.2m³/s)

Diversion tunnel	Inlet bottom Elevation (m)	Outlet bottom Elevation (m)	Upstream water level (m)	Downstream water level of Diversion tunnel outlet (m)	Discharge coefficient	Flow (m ³ /s)
	1244.5	1231	1262.3	1239.3	0.6136	297.57

Cofferdam	Crest Elevation (m)	Upstream water level (m)	Average Width (m)	submergence coefficient	Discharge coefficient	Average flow velocity of cofferdam crest (m ³ /s)	Contracted water depth (m) of cofferdam foot downstream(EL.1245.0)	Maximum flow Velocity(m/s) of cofferdam foot downstream(1245.0)	Flow (m ³ /s)
	1253.0	1262.3	26	1.0	0.34	7.30	2.94	20.01	1529.63

Hydraulic Calculation of Diversion Tunnel

8 Conclusions

In conclusion, to summarize as aforementioned, during dry season, the water discharges from diversion tunnel, discharge of diversion tunnel is 208 m³/s. The corresponding inlet water level is at 1251.5m.

During flood season (1:5 AEP), the water discharges from upstream cofferdam and diversion tunnel, discharge of cofferdam and diversion tunnel is 1074.76m³/s and 292.54m³/s. The corresponding inlet water level is at 1260.5m.

During flood season (1:20 AEP), the water discharges from upstream cofferdam and diversion tunnel, discharge of cofferdam and diversion tunnel is 1529.63m³/s and 297.57 m³/s. The corresponding inlet water level is at 1262.3m.